

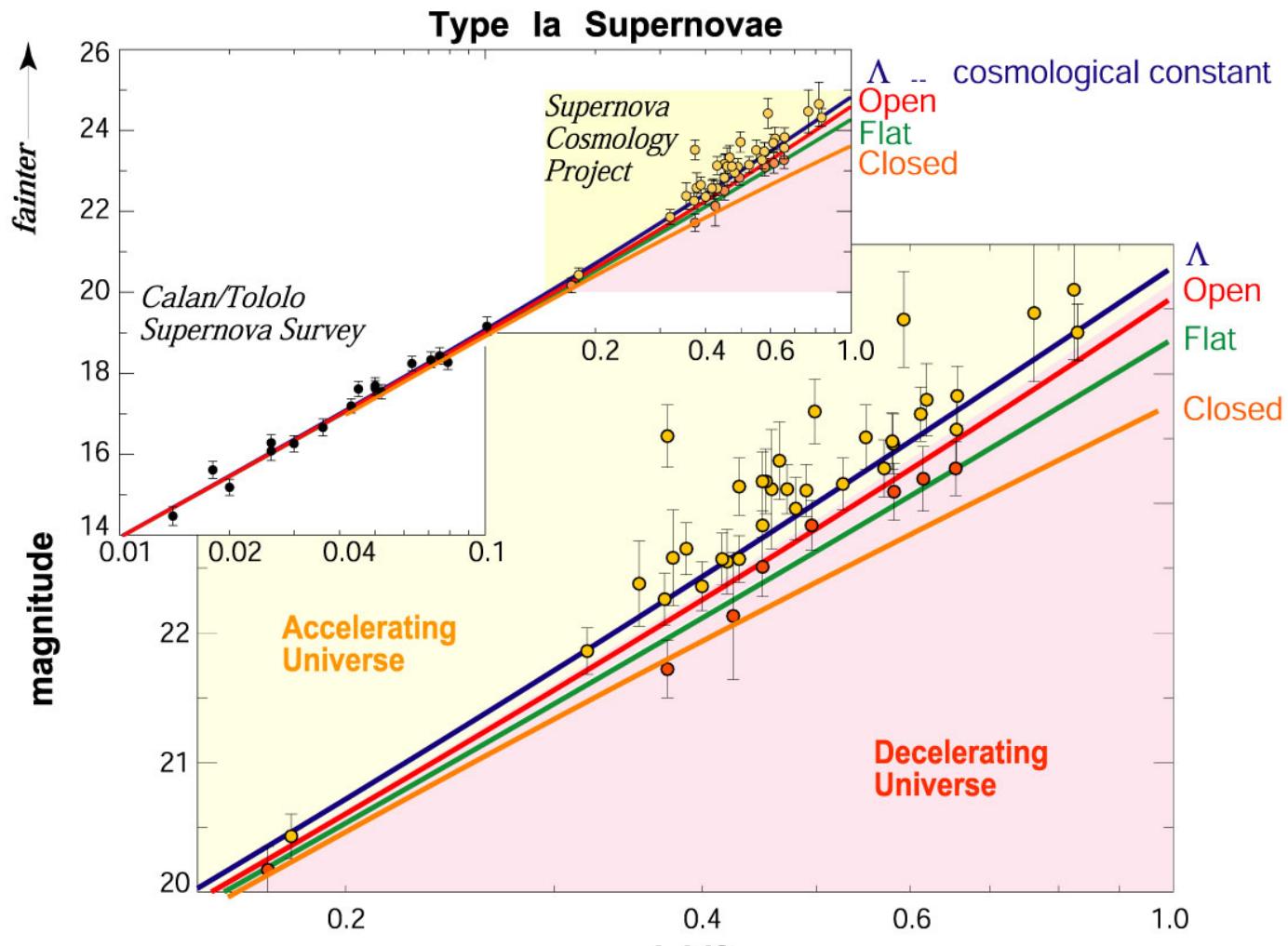
# **SNAP Telescope**

**M.Lampton**  
**Space Sciences Lab**  
**University of California Berkeley**

# Dark Energy Evidence

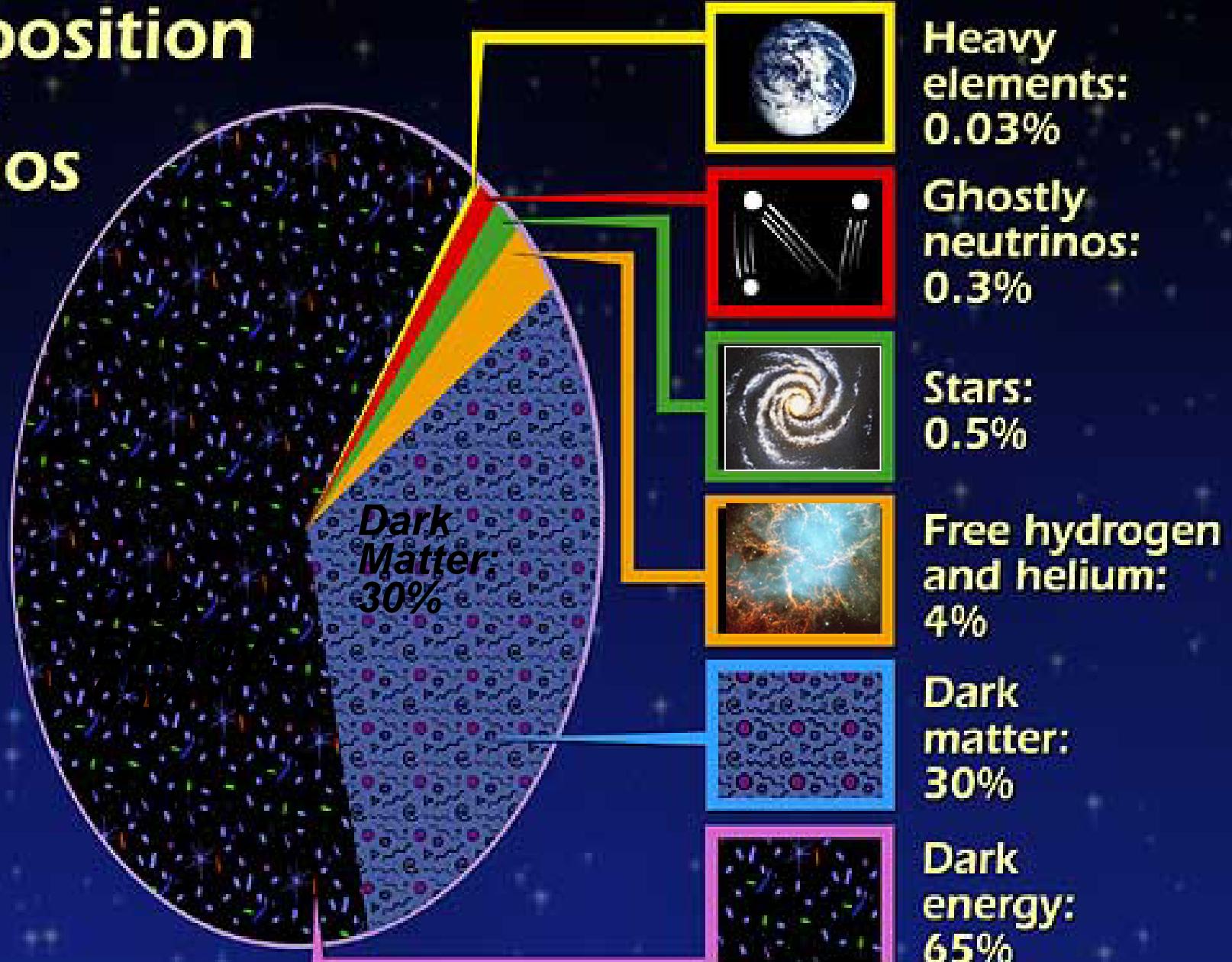


- 1998: Supernovae show the universe is accelerating
- 1999-2003: Corroboration from CMB and cluster masses



# *Energy budget of Universe*

## **Composition of the Cosmos**



# Implications....



The implications of an accelerating universe:

1. The expansion is not slowing to a halt and then collapsing (i.e., the universe is *not* "coming to an end").  
In the simplest models, it will expand forever.
2. There is a previously unseen energy pervading all of space that accelerates the universe's expansion.

This new accelerating energy ("dark energy") has a larger energy density than the mass density of the universe (or else the universe's expansion wouldn't be accelerating).

# What is Dark Energy?



- Not predicted by current theories of space/time/gravity
  - Yet one form is permitted by Einstein's general relativity
- Physicists propose a variety of alternative theories
  - Supergravity
  - Brane worlds with many higher dimensions
  - Vacuum metamorphosis
- Each theory raises profound questions about the nature of space, time, fundamental particles, and gravity
- Each theory has unique predictions for the observable history of the expansion of the universe
- SNAP is the best way known to measure this history

# The Next Level: Precision Cosmology

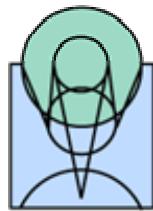


- A more accurate SN magnitude-redshift diagram:
  - Sufficient accuracy to distinguish models of Dark Energy
  - Photometry with 2% accuracy in each redshift bin
  - Spectroscopy with 1% redshift accuracy
  - Multicolor light curves to provide SN classification
  - Thousands of SNe => wide field “survey” type telescope
- Large redshift range
  - Z out to 1.7, when presumably gravity dominated dark energy
  - Takes us beyond atmospheric IR cutoff => space
- Eliminate/manage systematics
- Explore weak lensing to quantify cosmic mass budget
- Huge amount of observing time
  - Dedicated, well-calibrated => space
- Extremely dark skies => space

# SNAP Collaboration



Samuel Silver  
Space Sciences  
Laboratory



BNL: **G. Aldering, C. Bebek, J. Bercovitz, W. Carithers, C. Day, R. DiGennaro, S. Deustua\*, D. Groom, S. Holland, D. Huterer\*, W. Johnston, R. W. Kadel, A. Karcher, A. Kim, W. Kolbe, R. LaFever, J. Lamoureux, M. Levi, E. Linder, S. Loken, R. Miquel, P. Nugent, H. Oluseyi, N. Palaio, S. Perlmutter, K. Robinson, A. Spadafora H. von der Lippe, J-P. Walder, G. Wang**

UC Berkeley: **M. Bester, E. Commins, G. Goldhaber, S. Harris, P. Harvey, H. Heetderks, M. Lampton, D. Pankow, M. Sholl, G. Smoot**

U. Michigan: **C. Akerlof, D. Levin, T. McKay, S. McKee, M. Schubnell, G. Tarle, A. Tomasch**

Yale: **C. Baltay, W. Emmet, J. Snyder, A. Szymkowiak, D. Rabinowitz, N. Morgan**

CalTech: **R. Ellis, J. Rhodes, R. Smith, K. Taylor**

Indiana: **C. Bower, N. Mostek, J. Musser, S. Mufson**

JHU / STScI: **R. Bohlin, A. Fruchter**

U. Penn: **G. Bernstein**

IN2P3/INSU (France): **P. Astier, E. Barrelet, J-F. Genat, R. Pain, D. Vincent**

U. Stockholm: **R. Amanullah, L. Bergström, M. Eriksson, A. Goobar, E. Mörtzell**

LAM\*\*: **S. Basa, A. Bonissent, A. Ealet, D. Fouchez, J-F. Genat, R. Malina, A. Mazure, E. Prieto, G. Smajda, A. Tilquin**

FNAL\*\*: **S. Allam, J. Annis, J. Beacom, L. Bellantoni, G. Brooijmans, M. Crisler, F. DeJongh, T. Diehl, S. Dodelson, S. Feher, J. Frieman, L. Hui, S. Jester, S. Kent, H. Lampeitl, P. Limon, H. Lin, J. Marriner, N. Mokhov, J. Peoples, I. Rakhno, R. Ray, V. Scarpine, A. Stebbins, S. Striganov, C. Stoughton, B. Tschorhart, D. Tucker**

\*affiliated institution

\*\* pending

- **Light Gathering Power**
  - must measure SNe 4 magnitudes fainter than 26 magnitude peak
  - want SNR of 30:1 at peak brightness, aggregate exposure fit
  - presence of zodiacal light foreground radiation
  - time-on-target limited by revisit rate & number of fields
  - spectroscopy demands comparable time-on-target
  - requires geometric diameter  $\sim 2$  meters
- **Angular resolution**
  - signal to noise ratio is driver
  - diffraction limit is an obvious bound
  - Airy disk at one micron wavelength is 0.12 arcseconds FWHM
  - need to match this to pixel size of VIS and NIR detectors
- **Field of View**
  - determined by required supernova discovery rate
  - volume of space is proportional to field of view
  - one degree field of view will deliver the requisite discovery rate
- **Wavelength Coverage**
  - 0.35 to 1.7 microns requires all-reflector optical train

# SNAP Reference Model



Orbit:	HEO, elliptical, 3 day period (similar to AXAF/Chandra or XMM/Newton)
Working field of view:	0.7 square degrees
Survey fields:	7.5 square degrees near north ecliptic pole 7.5 square degrees near south ecliptic pole additional weak-lensing fields, ~300 sq degrees
Field revisit period:	approx 4 days
Time allocations:	50% survey, 36% spectroscopy, 14% downlink
Wavelength range:	0.35 to 1.7 microns
Telescope aperture:	2.0 meters

Sun is 90deg  
to view direction

These reference model parameters have been obtained through mission simulations that explore the cosmological parameter constraints – in particular, on acceleration versus redshift – that various mission scenarios would yield.

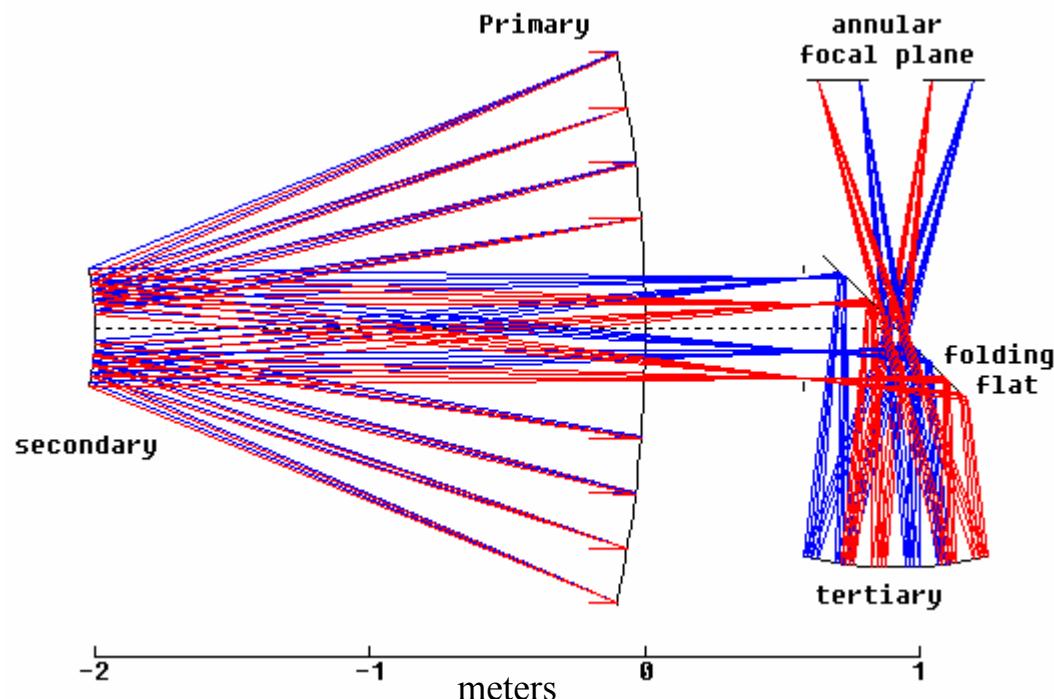
# Korsch AF-TMA configuration



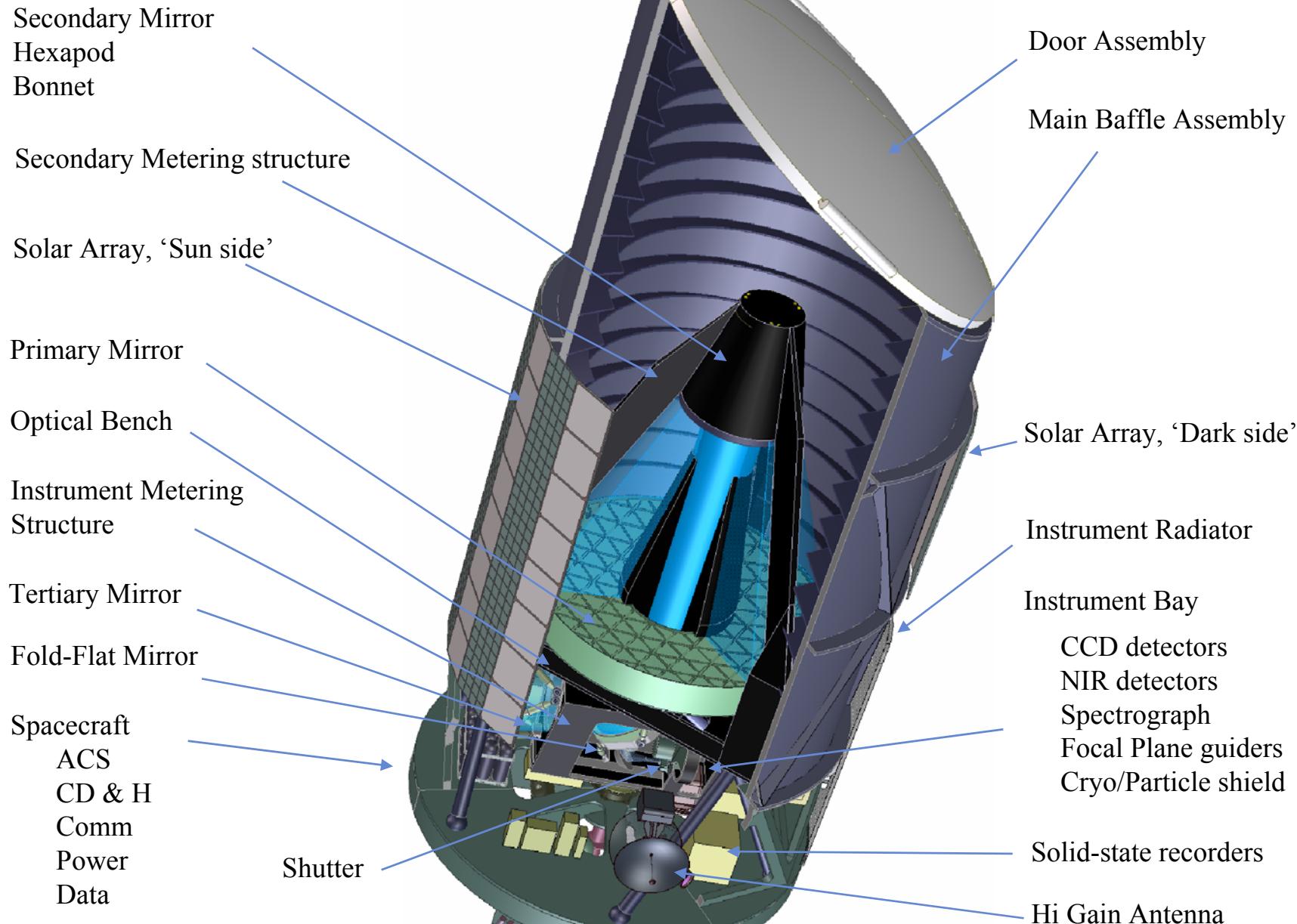
- Prolate ellipsoid concave primary mirror
- Hyperbolic convex secondary mirror
- Flat folding mirror with central hole
- Prolate ellipsoid concave tertiary mirror
- Delivers < 0.06 arcsecond FWHM geometrical blur over annular field 1.37 sqdeg
- Flat focal surface
- EFL adapts 15 to 30meters;  
baseline=21.66m
- Side-mounted detector
- Telephoto advantage = 7

Huge diffraction - limited field :

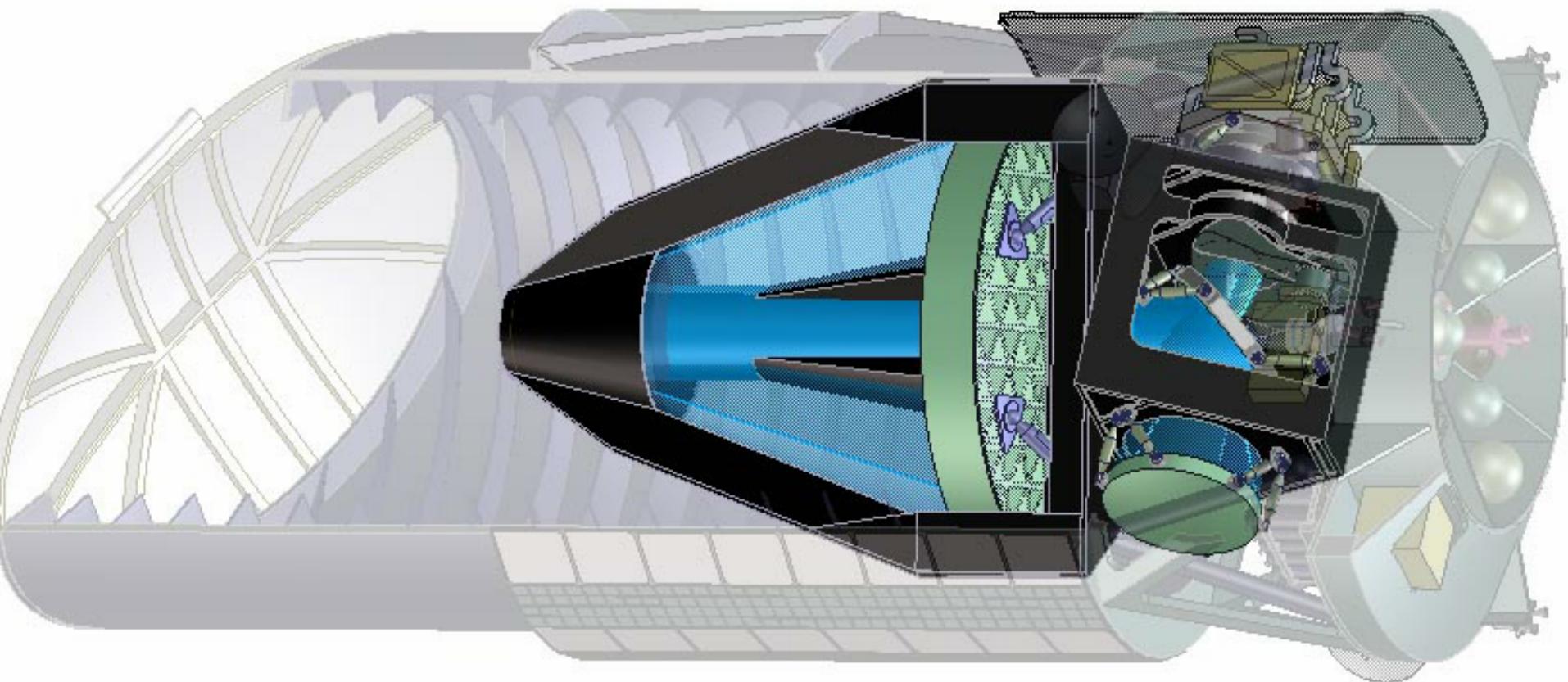
$$N_{\text{resolutionElements}} = \frac{\Omega_{\text{field-of-view}}}{\Omega_{\text{diffraction-blur}}} = 3E9 \text{ at } 0.5 \mu\text{m}$$



# Payload Layout



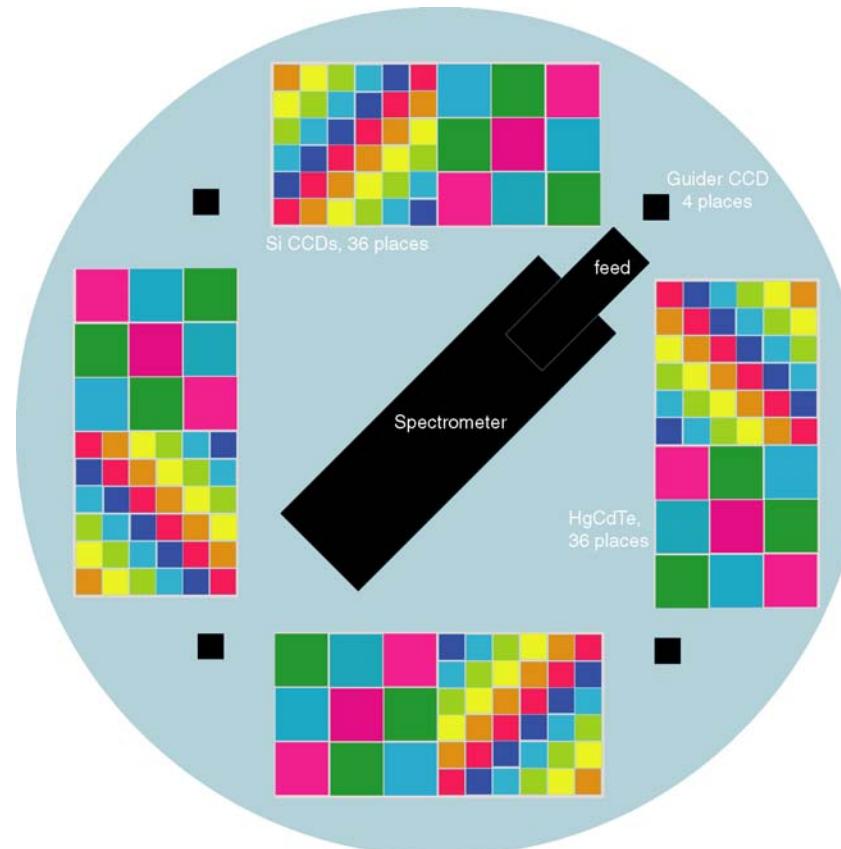
# Metering Configuration



# Focal Plane Concept



- Coalesce all sensors at one focal plane.
  - Imager sensors on the front.
    - 36 HgCdTe 2kx2k 18  $\mu\text{m}$
    - 36 CCD 3.5kx3.5k 10.5  $\mu\text{m}$
  - Filters
    - 1 of 3 per HgCdTe
    - 4 of 6 per CCD
  - Spectrograph on the back with access ports through the focal plane.
- Common 140K operating temperature.
- Dedicated CCDs for guiding from the focal plane.
- Exposure times of 300 s with four/eight exposures in CCDs/HgCdTe.
- 20 s readout slow enough for CCD noise and 4 post exposure and 4 pre exposure reads of HgCdTe.



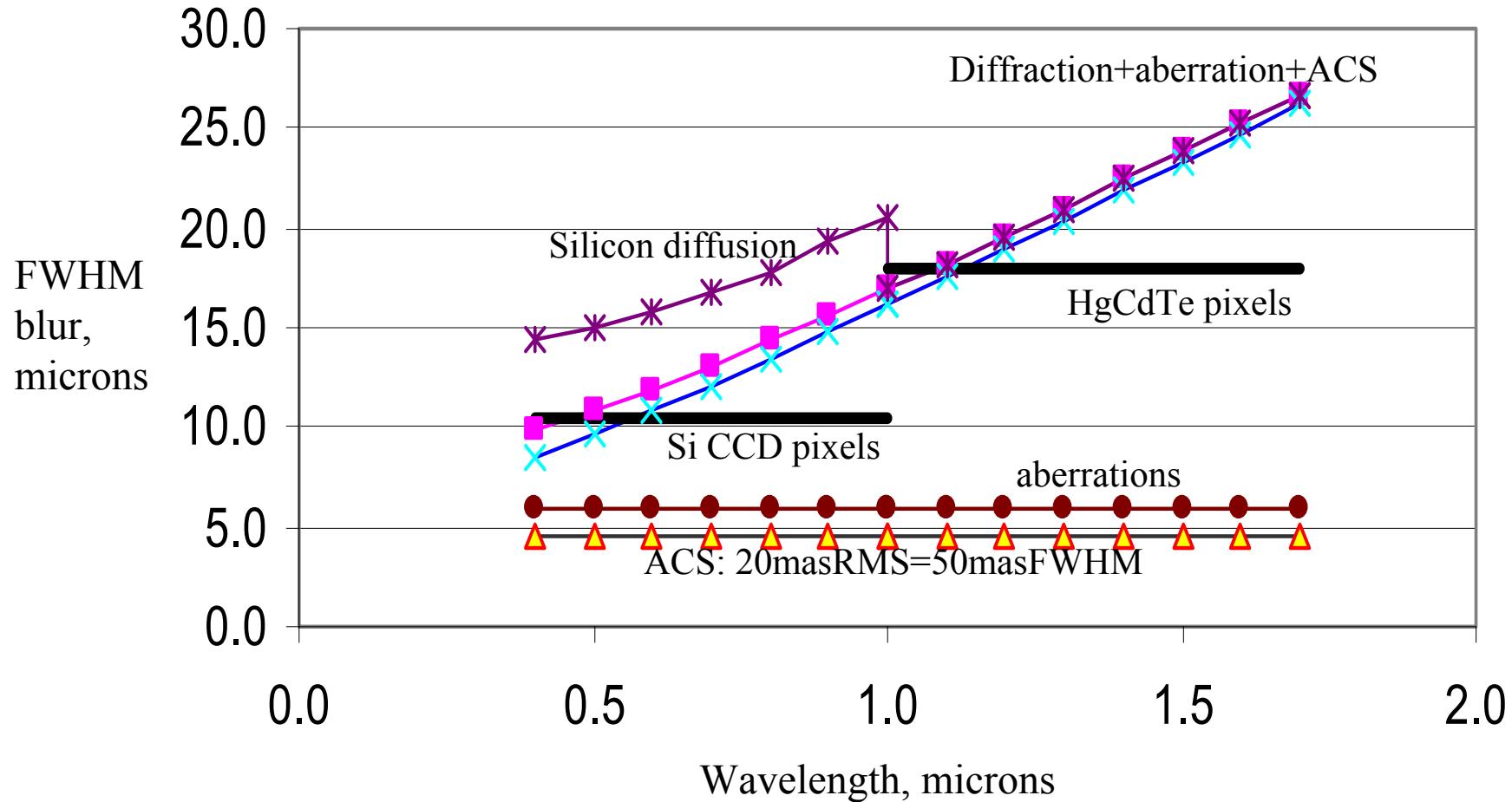
Bebek et al, 5164-10 [S3] Thursday

# Image Quality Issues



- **Image quality drives science SNR, exposure times, ....**
- **Many factors contribute to science image quality**
  - diffraction: size of aperture, secondary baffle, struts, ...
  - aberrations: theoretical imaging performance over field
  - manufacturing errors in mirrors
  - misalignments & misfocussing of optical elements
  - dirt, contamination, or nonuniformity in mirror coating
  - guiding errors
  - spacecraft jitter
  - detector issues
  - constancy of the PSF is important to the weak lensing science
- **Work has begun on a comprehensive budget**
  - ongoing simulation team efforts
  - Bernstein's “Advanced Exposure Time Calculator” PASP
  - telescope studies feed into the simulations

# Pixel sizes and blur sizes



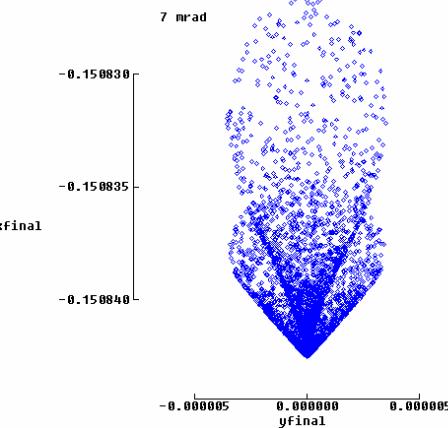
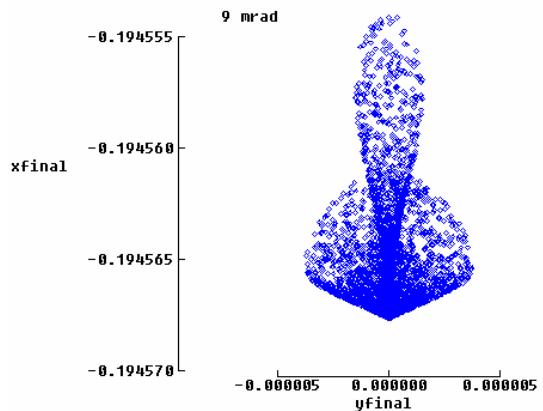
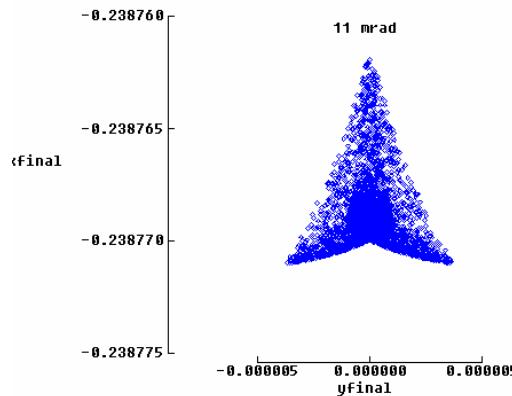
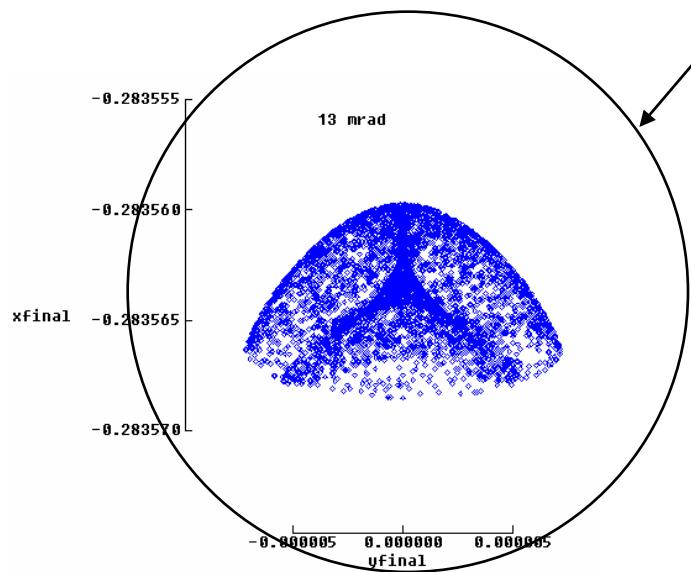
# Ray Trace Examples



## TMA62/TMA63 configuration

Airy-disk zero at one micron wavelength

26 microns diam=0.244arcsec



# Diffraction

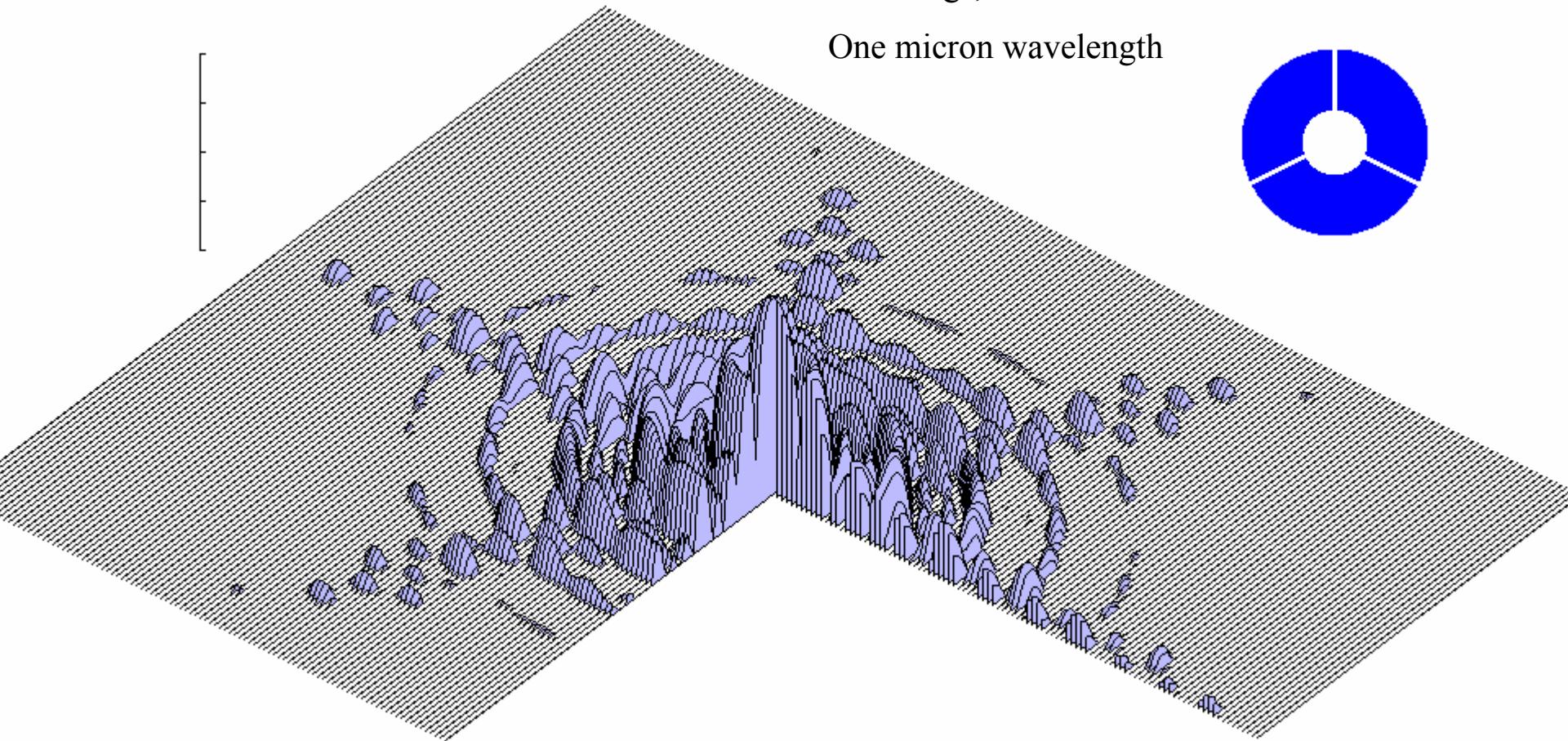
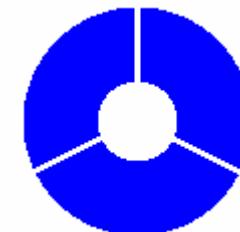


Circular 2m aperture

central 0.7m obscuration

Three legs, 50mm x 1meter

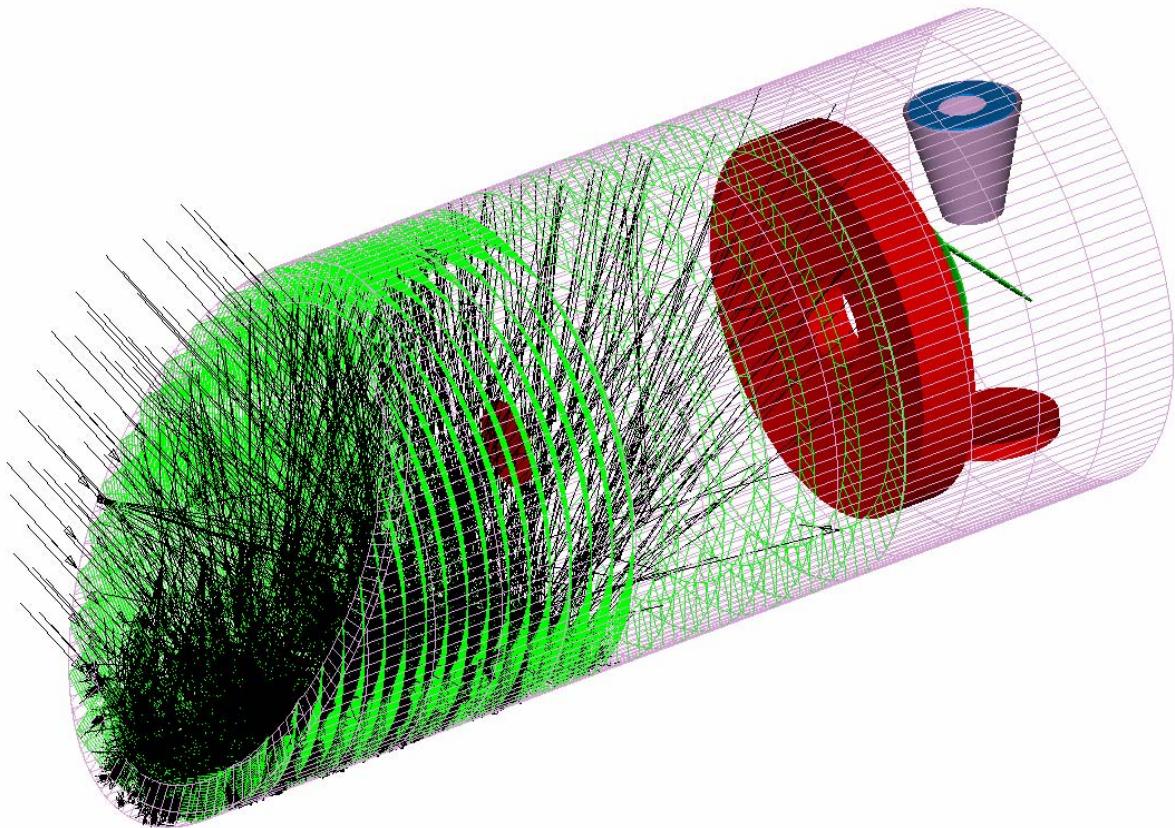
One micron wavelength



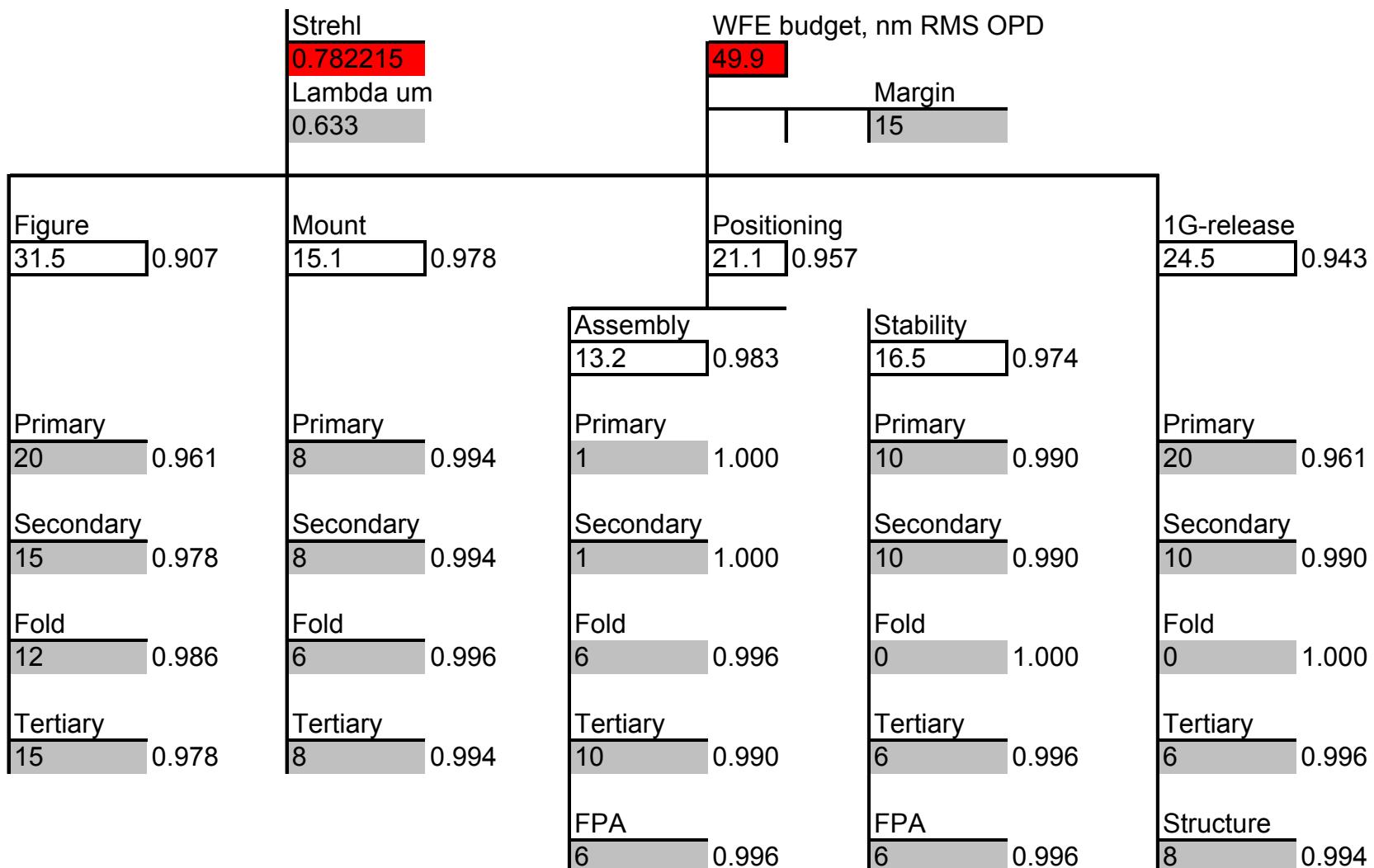
# ASAP Stray Light Model



- Harvey scattering  
Earthshine case shown
- Two baffle scatters and one PM scatter to reach focal plane
- Preliminary estimate:  
 $\frac{1}{2}$  zodi
- Anodized Al or Z306  
(no exotic coatings assumed)
- Continuing work to develop entire system including interior of cryostat



# Wavefront Error Budget



Marechal Relationship: Strehl= $\exp(-2 \pi/\lambda)^2 \phi^2$

Secondary is adjustable in five DOF

# Allowed temperature swings



Mirror CTE and thermal expansion change to ROC

OK=gray

	Guaranteed CTE (ppb/K)	Primary	Secondary	Tertiary	
ULE Premium (*)	40	2.6	22.7	89.3	$\Delta T$ (K)
ULE Mirror (*)	45	2.3	20.2	79.4	$\Delta T$ (K)
Zerodur (class 0)	20	5.1	45.5	178.6	$\Delta T$ (K)
Zerodur (class 1)	50	2.0	18.2	71.4	$\Delta T$ (K)
Zerodur (class 2)	100	1.0	9.1	35.7	$\Delta T$ (K)
SiC	2770	0.0	0.3	1.3	$\Delta T$ (K)
		4.9	1.1	1.4	R (m)
		0.5	1	5	$\Delta R$ ( $\mu$ m)

(\*) For all grades, CTE shall be  $0 \pm 30$  ppb/ $^{\circ}$ C over a temperature range of 5 to 35 $^{\circ}$ C, with a 95% confidence level.

(\*) Delta CTE = Variation of CTE measurements within a part as measured in the radial and axial direction.

# TMA63 Sensitivity Table



Primary Mirror (incoming light at U=0.3435°)											
Shifts			Rotations			Centroid Motion (local coordinates)			Spot Size (local coordinates)		
$\Delta X$	$\Delta Y$	$\Delta Z$	$\Delta\Theta_x$	$\Delta\Theta_y$	$\Delta\Theta_z$	X	$\Delta X$	Y	$\Delta Y$	Xrms	Ratio
μm	μm	μm	μrad	μrad	μrad	μm	μm	μm	μm	μm	Ratio
0	0	0	0	0	0	-129017	0.00	0.00	0.00	2.98	1.00
10	0	0	0	0	0	-129102	-84.58	0.00	0.00	5.22	1.75
0	10	0	0	0	0	-129017	0.00	-83.97	-83.97	3.31	1.11
0	0	10	0	0	0	-129018	-0.51	0.00	0.00	19.15	6.42
0	0	0	10	0	0	-129017	-0.01	421.16	421.16	4.67	1.57
0	0	0	0	10	0	-129442	-424.24	0.00	0.00	8.66	2.91
0	0	0	0	0	10	-129017	0.00	0.00	0.00	2.98	1.00

Secondary Mirror											
Shifts			Rotations			Centroid Motion (local coordinates)			Spot Size (local coordinates)		
$\Delta X$	$\Delta Y$	$\Delta Z$	$\Delta\Theta_x$	$\Delta\Theta_y$	$\Delta\Theta_z$	X	$\Delta X$	Y	$\Delta Y$	Xrms	Ratio
μm	μm	μm	μrad	μrad	μrad	μm	μm	μm	μm	μm	Ratio
0	0	0	0	0	0	-129017	0.00	0.00	0.00	2.98	1.00
10	0	0	0	0	0	-128948	69.24	0.00	0.00	1.37	0.46
0	10	0	0	0	0	-129017	0.00	68.74	68.74	3.31	1.11
0	0	10	0	0	0	-129016	0.93	0.00	0.00	17.23	5.78
0	0	0	10	0	0	-129017	0.00	-77.70	-77.70	3.08	1.03
0	0	0	0	10	0	-128939	78.28	0.00	0.00	2.26	0.76
0	0	0	0	0	10	-129017	0.00	0.00	0.00	2.98	1.00

Tertiary Mirror											
Shifts			Rotations			Centroid Motion (local coordinates)			Spot Size (local coordinates)		
$\Delta X$	$\Delta Y$	$\Delta Z$	$\Delta\Theta_x$	$\Delta\Theta_y$	$\Delta\Theta_z$	X	$\Delta X$	Y	$\Delta Y$	Xrms	Ratio
μm	μm	μm	μrad	μrad	μrad	μm	μm	μm	μm	μm	Ratio
0	0	0	0	0	0	-129017	0.00	0.00	0.00	2.98	1.00
10	0	0	0	0	0	-128992	25.34	0.00	0.00	2.98	1.00
0	10	0	0	0	0	-129017	0.00	25.22	25.22	2.98	1.00
0	0	10	0	0	0	-129019	-1.82	0.00	0.00	3.40	1.14
0	0	0	10	0	0	-129017	0.00	-35.58	-35.58	2.98	1.00
0	0	0	0	10	0	-128981	35.89	0.00	0.00	2.94	0.99
0	0	0	0	0	10	-129017	0.00	0.00	0.00	2.98	1.00

CRITICAL

# Telescope Technology Roadmap



- Existing technologies are suitable for SNAP Optical Telescope Assembly
- New materials, processes, test & evaluation methods are unnecessary
- Mirror materials
  - science driver: \*stable\* figure to guarantee constant focus and PSF
  - Corning ULE glass: lightweight, but is assembled from faceplates and core components, hence requires bond strength verification.
  - Schott Zerodur glass/ceramic: widely used in ground based astronomical telescopes; one piece, but open-back LW is heavier.
- Metering structure materials
  - science driver: \*stable\* structure for constant focus and PSF
  - M55J carbon fiber + cyanate ester resin; epoxy adhesive bonds
- Mirror finishing technology
  - conventional grind/polish/figure using abrasives
  - ion-beam figuring available from two vendors
- Mirror surface metrology
  - same as other space telescopes, e.g. cassegrains
  - standard interferometer setups will do the job for SNAP

# Trade Studies Summary



- Trade Studies worked during Pre-R&D Phase
  - Optical configuration: >>TMA
  - Warm optics vs cold optics: >>warm
  - integrated sensor array vs separated: >>integrated
- Trade Studies continuing through R&D Phase 2003-2005:
  - Exact aperture: cost & schedule vs aperture
  - Wavefront error: cost vs performance
    - focal length: is 21.66m the best choice?
    - pupil obscuration, diffraction, stray light...
  - Primary mirror design, stiffness, mass trade
  - Built-in test equipment to allow frequent end-to-end checks
  - Vendor-dependent issues
    - mirror material: ULE? Zerodur?
    - Test plans: gravity unloading scheme
    - Test plans: full aperture vs partial aperture
      - Buy, borrow, rent the flat
      - How to do the stitching

# SNAP Schedule



Date \ Tasks	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	
Project Flow	Formulation					Implementation				
	Pre-Phase A	Phase A	Phase B	Phase C/D			Phase E			
	Preconceptual Planning	Conceptual Design	Preliminary Design	Construction			Operations			
Project Milestones	CD-0	ZDR DRR	CDR SRR CD-1	PDR	FDR		SAR	Inst. Del. FRR Launch	CD-4	
Instruments	Instrument Concept Development			PDR	FDR CD-3b		Inst. I&T	Delivery		
Long Lead Procurements	LLP/CD-3a			Detectors		Mirrors				
Spacecraft	S/C RFP S/C Study-A			S/C Selection		Design	Build	I&T		
Telescope	OTA RFP OTA Study			OTA Selection		Design	Build	I&T		
Ground Sys. (MOC & SOC)						Design	Build	I&T		
Launch Vehicle				Launch Vehicle Procurement						

CDR - Conceptual Design Report  
 FDR - Final/Critical Design Review  
 ZDR - Zeroth Order Design Report  
 PDR - Preliminary Design Review

DRR - Draft Requirements Review  
 SRR - Systems Requirement Review  
 LLP/BR - Long Lead Procurement Budget Req.

SAR - System Acceptance Review  
 FRR - Flight Readiness Review

# Conclusions



- **Baseline Requirements**
  - Somewhat less demanding than HST: we are NIR not NUV
  - But – no astronaut servicing available
- **Baseline Design**
  - annular field three-mirror anastigmat
- **Working towards a biddable requirements document**
  - vendor participation in 2004-05
- **Schedule risks: OTA is a long lead item!**
- **No new optics technology is required**
- **Budgets and Plans**
  - tolerances
  - stray light
  - fab plan
  - test plan
- **Visit us at....**      <http://snap.LBL.gov>